

An insight on the thermo-mechanical behaviour of deep core hybrid moulds

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Abstract

Precision products are coming into the market after increasingly shorter periods of development and production. This implies reduced design periods for the products and the tools. The mouldmaking industry is facing this reality by integrating the stages of conception, development and tool manufacturing in the design process. This integration use alternative fabrication technologies employed in rapid prototyping and tooling. Shorter lots of plastic components are consequently becoming possible through the use of hybrid moulds that use alternative non-metallic/metallic materials in the moulding blocks. The consideration of the wear and thermal characteristics of the moulding blocks are important for guaranteeing the precision performance of the hybrid moulds.

The implementation of CAE tools during the development of an injection mould for a new product has already shown advantages. They can be used to foresee the mould behaviour during the injection moulding process without even start building the tool and minimise the risk of mistake during the design process.

Aspects associated to the design and performance of an injection hybrid mould for a deep part are considered in this paper. Conventional Machining, Resin Casting and Prometal technologies were used to produce the moulding cores. In particular, the mechanical and the thermal behaviour of these hybrid components were assessed and compared with CAE simulations. The injection moulding programme was carried out with unreinforced polypropylene.

Introduction

The mould making industry has been pressed with the need of rapidly introducing new products in the market, with shorter life cycle, which leads to smaller development periods and production runs [1, 2].

These competitive factors, life cycle reduction and high variety of products, led to the development of rapid prototyping and rapid tooling technologies (RPT) with an increasing importance in this industry [3].

The objective of rapid and economically producing injection moulds for shorter runs suggested the integration of RPT with conventional manufacturing technologies. The concept of Hybrid Injection Moulds embodies the idea of assembling conventional metallic mould structures with moulding blocks obtained by RPT [4]. As hybrid moulds also aim at economic advantages their overall design process must be carefully considered in order to obtain the best price/performance ratio for the reduction of the time-to-market [5, 6].

In the design process, the assessment of the thermo-mechanical behaviour is essential for the improvement of the tool performance, as well as, costs, tool life time and accuracy aspects. Therefore, it is important to predict the influence in the injection process and final part properties of using non-metallic materials in the moulding blocks [4, 7].

Experimental programme

The main objective of this study was the evaluation of the thermo-mechanical performance of moulding blocks manufactured by conventional and rapid tooling techniques.

It was also envisaged the study of the influence on the part shrinkage of the moulding block material. The metrology assessment was made with a 3D measuring machine, 2 hours after injection moulding the parts.

The work was developed in two phases: a CAE analysis, using the package *Moldex 3D* (CoreTech System Co., Ltd, Hsinchu, Taiwan), to predict the injection moulding process when different core materials were used, and experimental moulding tests using a unreinforced polypropylene from *DOMO* – Domolen 1100 N.

The main properties of the moulding material are presented in *Table 1*.

Table 1 – Properties of the injection moulding material

DOMOLEN 1100 N	
Density (Mg/m ³)	0,91
MFR (g/10 min) [230°C/2.16kg]	12
Tensile Modulus of Elasticity (MPa)	1550
Tensile Yield Stress (MPa)	35

The processing conditions used in the experimental study are shown in *Table 2*.

Table 2 – Injection moulding conditions

Processing Program Conditions		
Melt temperature (°C)	230	
Mould temperature (°C)*	30	50
Holding pressure (MPa)**	22	29
Holding time (s)	10	
Cooling time (s)	20	

* Temperature of the water circuit

** Corresponding to 30 and 40 bar of hydraulic pressure of the injection machine

The moulding used in the experiments is a simple tube with a considerable height (60 mm), as presented in Figure 1.

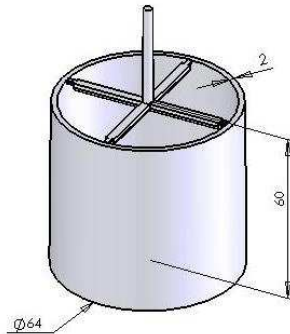


Fig. 1. Moulding of the case study

Injection mould

The hybrid mould for this study was designed to receive different interchangeable core and cavity blocks, made by conventional machining and RPT. Specific aspects of the mould design were considered to facilitate and guarantee the interchangeability of the various moulding blocks. A schematic view of the tool is shown in Figure 2.

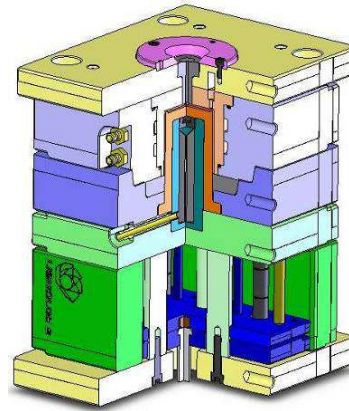


Fig. 2. Hybrid Mould of the case study

The adopted solutions related with the moulding blocks and the cooling system are:

- Core and cavity blocks supported by the respective retainer plates, to avoid the direct screwing of the moulding blocks. This is required because of the limited strength of the resins to be used;
- In the cavity side, the water circuit was machined directly in the cavity retainer plate to avoid the machining of the cavity block, as well as the O-rings housing;
- In the core side, the cooling system consists of an independent baffle-type system that is assembled on the mould structure. This solution avoids the costly and delicate machining of the cooling channels inside the resin core.

Manufacturing of moulding blocks

The core and cavity elements were manufactured in different materials and using various technologies, with the objective of studying their thermal and mechanical behaviour.

Conventional Machining

The core and cavity blocks were manufactured in tool steel (1.2312), known for its excellent machinability and uniform hardness. The shape of these blocks enabled the machining by turning.

Epoxy tooling

The commercial resin *Neukadur VG SP 5* from *ALTROPOL*, a high performance and heat resistant material specially developed for injection mould prototypes, was used to produce the core block. This epoxy resin is filled with mineral and metallic fillers that confer an improvement of the mechanical and thermal properties of the casting compound [8].

3D – Printing: Prometal

A Prometal core was developed using a S4 420 material, a stainless steel bronze infiltrated, with properties similar to P-20 steels, and improved thermal transfer.

The main properties of the used moulding blocks materials are presented in *Table 3*.

Table 2 – Properties of the moulding blocks materials

Materials	Prometal		
	Steel (1.2312)	(S4 420: 60% Stainless Steel + 40% Bronze)	Neukadur (Resin Casting)
Properties			
Density (Mg/m ³)	7,85	8,07	2,7
Hardness	55 HRC	26 HRC	90 Shore-D
Tensile Strength (MPa)	≈ 1000	682	50
Modulus of Elasticity (GPa)	200	147	9,8
Coefficient of Thermal Expansion (x10 ⁻⁶ °C)	12,9	7,2	30-35
Thermal conductivity (W/m.K)	36,5	85	0,7

Mould Instrumentation

To monitor the behaviour of the various moulding blocks the used mould was instrumented for pressure and temperature determination in the core and cavity. The cavity was instrumented with a thermocouple and a pressure sensor near the gate zone (Figure 3).

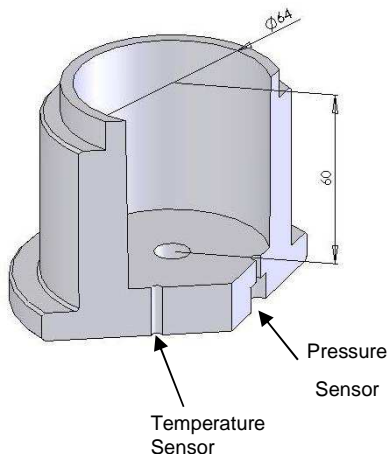


Fig. 3. Temperature and pressure sensors location in the cavity block

The core was monitored with temperature sensors across the core thickness (Figure 4), for a better understanding of its thermal behaviour. This is critical due to the moulding shrinkage over the deep core.

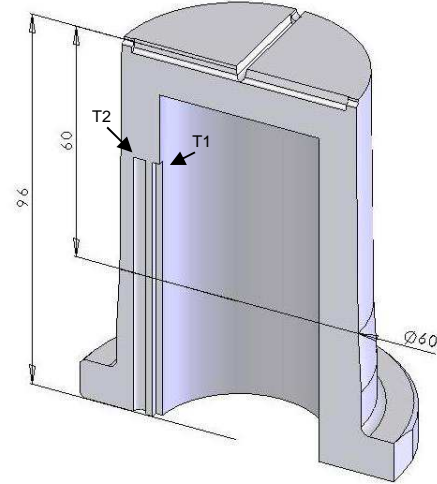


Fig. 4. Temperature sensor location in the core block

Thermo-mechanical environment and shrinkage

The effect of the shrinkage in the dimensional precision is of great importance in the quality of the injection moulded part. Therefore, the study of this effect is very important when producing injection moulded parts, using alternative mould materials with thermal properties different from conventional steel moulds. Thus, the work herein intends to establish the effects of the thermal conditions on part shrinkage, associated to the different materials used in the injection mould.

The process conditions that affect most the shrinkage are the holding pressure, the melt and mould temperatures. The parameter that presents higher influence on the part shrinkage is the holding pressure, which lowers the shrinkage when it increases. It was also shown that the holding pressure has different effects along the flow length, which is more evident in locations away from the gate [9].

Results and Discussion

CAE Simulations

Moldex 3D was the CAE simulation package for injection moulding process prediction of the plastic part, using the various moulding cores. Using the *Moldex 3D* program, the model mesh is imported from the *Rhinoceros* CAD tool to start the simulation (figure 5). All the conditions necessary

to run the injection moulding process simulation are specified, namely: part and mould materials, injection moulding machine, processing parameters and envisaged type of analysis.

Moldex3D

Model_Shaded Model

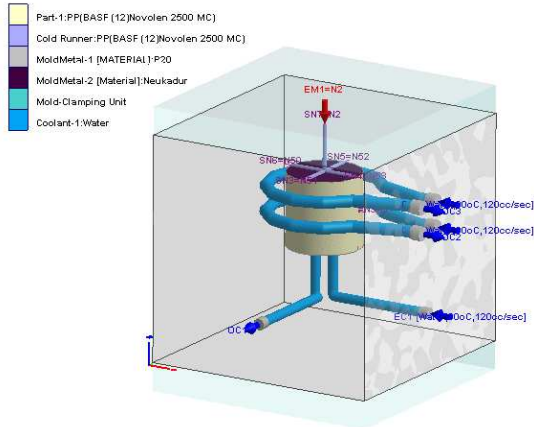


Fig. 5. – Mesh Model exported to Moldex 3D

Figures 6 and 7 shows the results obtained for the pressure and temperature profiles using one of the sets of the moulding blocks (steel-resin).

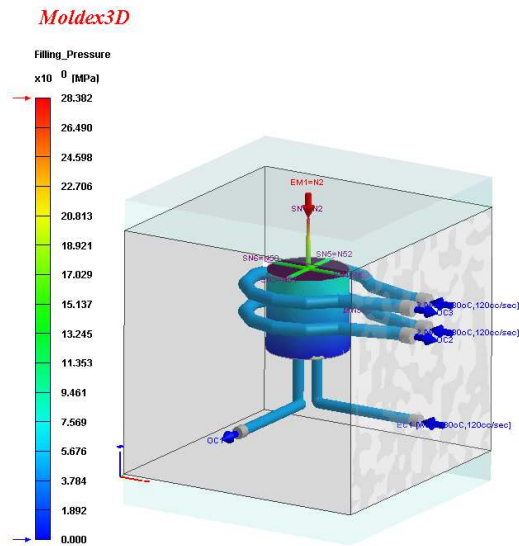


Fig. 6. – Pressure Profile in the Filling Phase

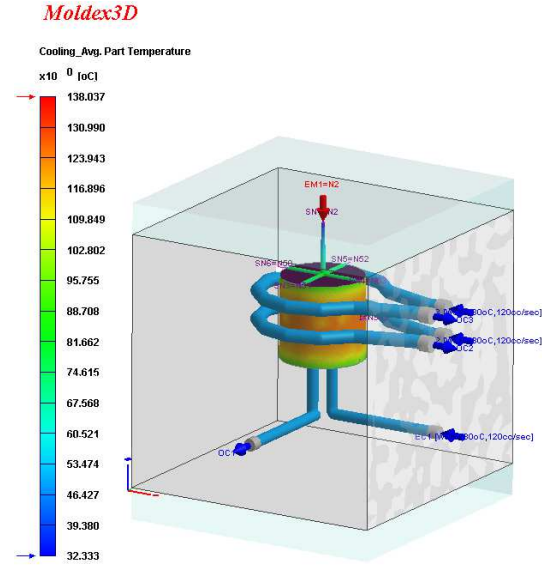


Fig. 7. – Temperature Profile at the Cooling Phase

The thermal results from the simulation are shown in figure 8 for the three different sets of moulding blocks (cavity-core): steel-steel, steel-Prometal and steel-resin.

According to the simulation results, the three temperature profiles are distinct. This is more evident in the case of the resin core, which is expectable, due to its extremely lower thermal conductivity, when compared with steel and Prometal (see Table 3).

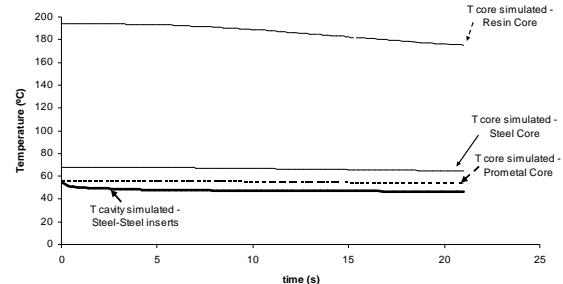


Fig. 8. Temperature predictions with Moldex 3D

Injection Moulding Tests

In order to assess the thermo-mechanical behaviour of the hybrid mould, three different sets of moulding runs were performed, varying the core material: steel, Prometal and epoxy resin. The mouldings were made in polypropylene. To analyse the effect of the mould material on the part shrinkage, two parameters were set as variables for this study: holding pressure (22 MPa and 29 MPa) and mould temperature (30°C and 50°C in the water circuit). The pressure and temperature data were recorded for this processing conditions and the results obtained presented in figures 9 to 11.

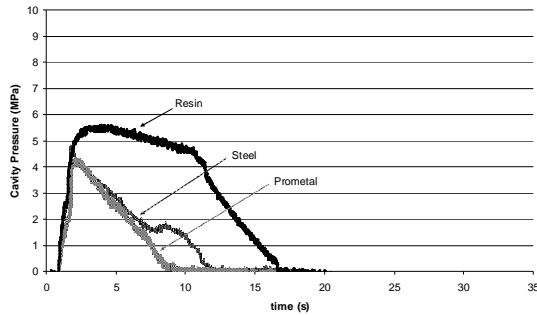


Fig. 9. Cavity pressure data for a holding pressure of 22 MPa and a mould temperature of 50°C

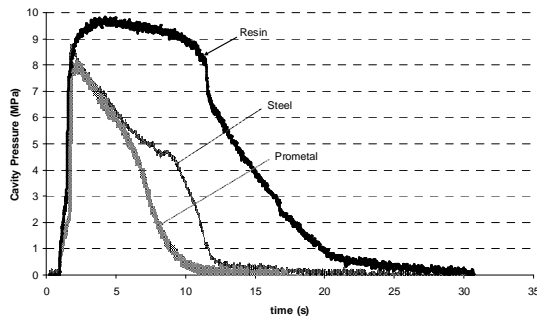


Fig. 10. Cavity pressure data for a holding pressure of 29 MPa and a mould temperature of 50°C

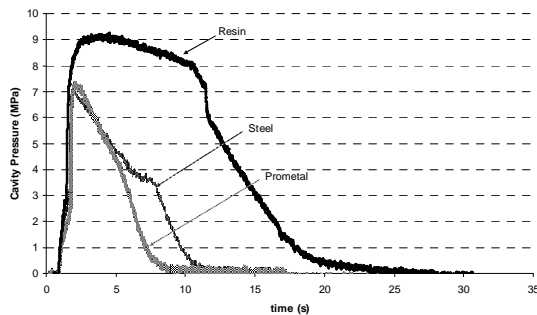


Fig. 11. Cavity pressure data for a holding pressure of 29 MPa and a mould temperature of 30°C

As expected, the increase of the holding pressure raises the cavity pressure, as it shown in figures 9 and 10. However, the cavity pressure profile diverges in the various core materials, this being more evident for the epoxy resin, where higher values of pressure were obtained. This result can be explained by the lower thermal conductivity of the resin, which causes a delay on the solidification of the plastic part.

The influence of the mould temperature in the cavity pressure can be observed in the figures 10 and 11. For the three core materials, there was no large difference in the cavity pressure upon increasing the mould temperature.

Figures 12 and 13 shows the different temperature profiles among the core thickness, at the locations T1 and T2, demonstrating the diverse thermal behaviour, mainly in the resin core, indicating a clear delay in the temperature recovering, due to its obviously lower thermal conductivity, when compared with the steel and Prometal materials.

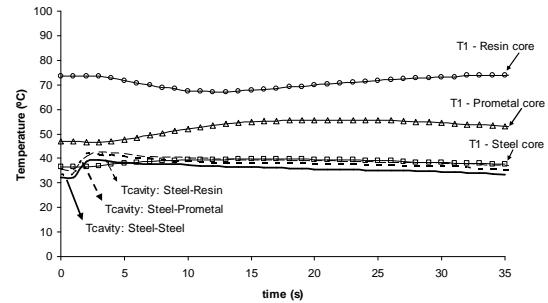


Fig. 12. Temperature data for the various materials at location T1, using the cavity temperature as reference (holding pressure=29 MPa; mould temperature=30°C).

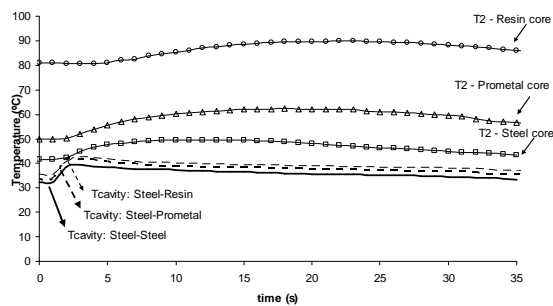


Fig. 13. Temperature data for the various materials at location T2, using the cavity temperature as reference (holding pressure=29 MPa; mould temperature=30°C).

Figure 14 represents the comparison between the simulation results (represented by lines) and experimental results (represented by lines with points), in the three sets of moulding blocks: steel-steel, steel-Prometal and steel-resin.

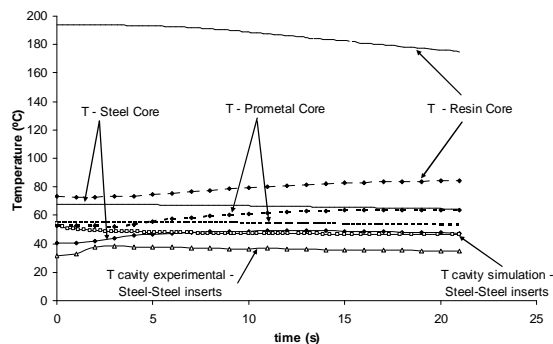


Fig. 14. Temperature data: comparison between *Moldex 3D* simulation and experimental results

In the assessment of the influence of the holding pressure and the mould temperature in the part shrinkage (figures 15 to 17) it was observed that the variation of the holding pressure and the mould temperature did not cause considerable differences.

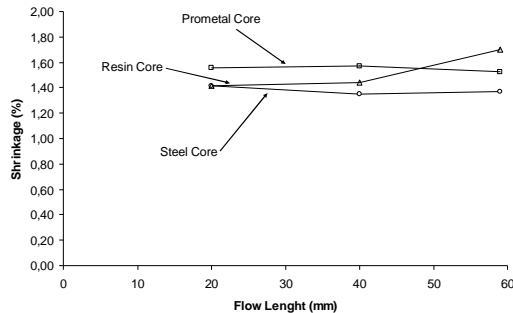


Fig. 15. Variation of shrinkage along the flow length (holding pressure=22 MPa; mould temperature=50°C)

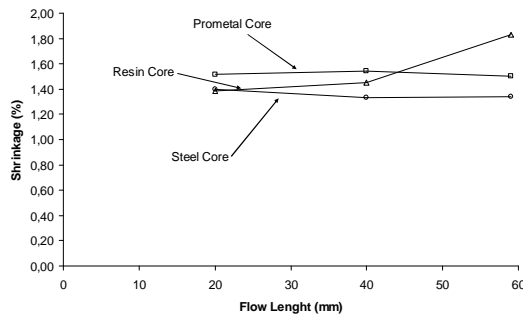


Fig. 16. Variation of shrinkage along the flow length (holding pressure=29 MPa; mould temperature=50°C)

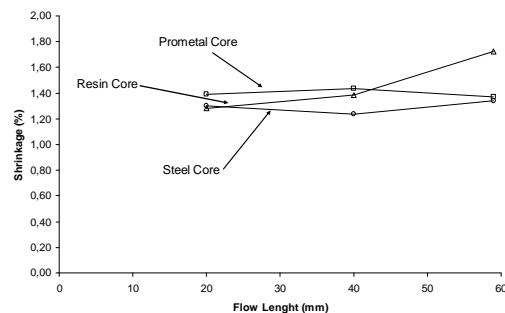


Fig. 17. Variation of shrinkage along the flow length (holding pressure=29 MPa; mould temperature=30°C)

However, observing in detail the figures 15 and 16, it is seen that the increase of the holding pressure caused higher variation in the shrinkage of the resin core moulded parts.

Conclusions

From the results of the injection moulding tests the holding pressure is the processing condition that

causes higher variations in the cavity pressure behaviour and in the part shrinkage.

The differences obtained were more evident in the epoxy core, due to its lower thermal conductivity.

The simulation with *Moldex 3D* adequately predicted the behaviour of a steel mould, but produced large differences for RP materials. This is may be due to the inaccurate thermal characterisation of the epoxide composite and the sintered Prometal.

Acknowledgments

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Keywords

Injection Mould Design, Rapid Tooling, Hybrid Mould, CAE.

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